Analysis of Mouchot

Jed Margolin

U. S. Patent 4,940,972 **Method of representing a perspective image of a terrain and a system for implementing same** issued July 10, 1990 to Mouchot, et al.

The following is presented in Mouchot '972 as prior art embodied in French Patent Application No. 2,524,177.

Column 1, lines 6 – 46:

> The present invention relates first of all to a method of representing, on a given flat support (i.e display device) and in perspective from a given point of observation, the image of a ground terrain known by the coordinates of the nodes of a given mesh network, in which a surface passing through these nodes is determined by interpolation. An assembly of points on the surface is determined and the pixels of the image to be represented, which are associated with this assembly of points, are illuminated so as to display the image on the display device screen.
>
> The invention applies in particular to the presentation, to the pilot of an aircraft, of a synthetic image of the ground terrain over which he is flying or, to the driver of a land vehicle, of a synthetic image of the site in which he is travelling, whatever the conditions of visibility. The invention also makes possible the presentation of images of real or fictitious sites for the purposes of simulation.
>
> In the case of assisting piloting and navigational tasks, the coordinates of the nodes of the mesh network are stored in a memory filled from a data base available for example from the National Geographical Institute. Such a data base contains the altitude of nodes obtained by sampling the terrain every three seconds of an arc, in latitude and in longitude, i.e. about 65 m in latitude and 92 m in longitude for the French territory. The point of observation, as well as the flat support on which the image is represented, depend on the position of the aircraft with respect to the ground, as well as its attitude so that, for example, the image represented corresponds as well as possible to what the pilot may see from his cabin under good conditions of visibility. A processing circuit, connected to the memory storing the coordinates of the nodes of the network and receiving the data from the instruments measuring the position and attitude of the aircraft, then determines the image pixels to be illuminated and consequently controls a display device disposed in front of the pilot.

Column 2, lines 31 – 40:

> The invention provides then a method of the above defined type, wherein a planimetric map or photograph of the ground is defined with color information, the map is digitized so as to obtain map pixels of given colors, the points of said assembly of points being defined so that they are all associated respectively with all the pixels of the image, with each of all these points, and so with each of the image pixels, a map pixel is associated and each image pixel is illuminated in the color of the associated map pixel.

The English translation of the English translation of the original French:

1. representing, on a given flat support (i.e display device) [Column 1, lines 8 – 9]

Something will be displayed on a monitor.

2a. in perspective from a given point of observation [Column 1, lines 9 – 10]

2b. The point of observation, as well as the flat support on which the image is represented, depend on the position of the aircraft with respect to the ground, as well as its attitude so that, for example, the image represented corresponds as well as possible to what the pilot may see from his cabin under good conditions of visibility. [Column 1, lines 34 – 38]

2c. A processing circuit, connected to the memory storing the coordinates of the nodes of the network and receiving the data from the instruments measuring the position and attitude of the aircraft, then determines the image pixels to be illuminated and consequently controls a display device disposed in front of the pilot. [Column 1, lines 40 – 46]

It will be displayed in perspective from a given point of view. There are many types of graphics perspectives and the nature of the perspective is not yet defined. The flexibility of the point of view has also not yet been defined.

3a. image of a ground terrain known by the coordinates of the nodes of a given mesh network, [Column 1, lines 11 – 14]

and

3b. In the case of assisting piloting and navigational tasks, the coordinates of the nodes of the mesh network are stored in a memory filled from a data base available for example from the National Geographical Institute. Such a data base contains the altitude of nodes obtained by sampling the terrain every three seconds of an arc, in latitude and in longitude, i.e. about 65 m in latitude and 92 m in longitude for the French territory. [Column 1, lines 27 – 34]

A digital elevation database is involved.

4. in which a surface passing through these nodes is determined by interpolation. [Column 1, line 12 – 14]

The surface passing through the elevation points is determined (created?) by interpolation.

The ‘972 improves upon the prior art [Column 2, lines 31 – 40]:

> The invention provides then a method of the above defined type, wherein a planimetric map or photograph of the ground is defined with color information, the map is digitized so as to obtain map pixels of given colors, the points of said assembly of points being defined so that they are all associated respectively with all the pixels of the image, with each of all these points, and so with each of the image pixels, a map pixel is associated and each image pixel is illuminated in the color of the associated map pixel.

Column 2, lines 41 – 46:

> In the method of the invention, on the perspective image of the ground is superimposed a digitized planimetric map of this ground. By planimetric map is meant here a conventional type map, such as a road map or an ordnance survey map, but also an aerial photograph or a satellite view at vertical incidence. Such digitized maps are available for example from the National Geographical Institute. Naturally, the word "color"

> is to be interpreted here in the wide sense, i.e. corresponding either to a multicolor representation or to a representation of black and white type, comprising a scale of grey levels.

A planimetric map that is defined with color information is a flat color map, such as a color road map.

A photograph of the ground defined with color information is a color photograph. It may be "an aerial photograph or a satellite view at vertical incidence" which means looking straight down. (When imaging large areas it is inefficient to only take images looking straight down so images taken at a slant are ortho-rectified, which means using a computer to correct the image to what it would look like if it had been taken looking straight down.)

Digitize the flat color map or color photograph.

The terms used in Mouchot are wonky. In addition to the difficulties in translating the terms from the original French, the current meanings of these terms are often much more precisely used today than they were in 1988 when the patent application for '972 was filed.

An example of the difficulties in the French translation is the use of the word *altitude* to mean *elevation*. Column 1, lines 27-34:

> In the case of assisting piloting and navigational tasks, the coordinates of the nodes of the mesh network are stored in a memory filled from a data base available for example from the National Geographical Institute. Such a data base contains the <u>altitude</u> of nodes obtained by sampling the terrain every three seconds of an arc, in latitude and in longitude, i.e. about 65 m in latitude and 92 m in longitude for the French territory.

Column 4, lines 48 – 55:

> The <u>altimetric</u> information includes the coordinates of nodes N of a mesh network obtained by sampling the ground every 3 seconds of an arc, i.e., and as was mentioned above, about 65 m in latitude and about 95 m in longitude. For each of these nodes, in a trirectangular reference frame OX, OY, OZ related to the ground, the coordinate of latitude X, the coordinate of longitude Y and the <u>coordinate of altitude</u> *Z* are known.

Also note that "trirectangular reference frame OX, OY, OZ" means "Cartesian coordinate reference frame OX, OY, OZ." (Cartesian coordinates were invented in the 17th century by René Descartes, a Frenchman. How could Mouchot's translators not know that?)

Column 5, lines 8 – 17, 20:

> Because the <u>altitude</u> of ground 2 is only known for nodes N and since, as will be seen further on, it will be useful to know this <u>altitude</u> for certain points which do not necessarily coincide with nodes N, a known surface 3 is determined everywhere approximately matching the shape of ground 2. For that, and in a way known per se, a surface 3 is defined by interpolation from the coordinates of nodes N.
>
> In FIG. 1, the surface 3 has been shown obtained by replacing each ground portion between three nodes by a flat triangular face. There naturally exist other types of interpolation which will be described hereafter, after a first general description of the method.

Column 8, lines 51 - 57

> Memory 11 contains <u>altimetric</u> data relating to the ground 2 over which the aircraft is flying. It has an input receiving an addressing signal SN and an output delivering a signal ZN. The addressing signal SN represents

> the coordinates X and Y of a node N of the mesh network and the output signals ZN represents the altitude Z of this node N.

In modern terms, Memory 11 contains elevation data.

The term altitude is used throughout the patent to mean elevation. Altimetric means having the properties of elevation.

What does the term "position" mean? Is it a 3D position as the term is commonly used today? Nope. Column 1, lines 35 – 41:

> The point of observation, as well as the flat support on which the image is represented, depend on the position of the aircraft with respect to the ground, as well as its attitude so that, for example, the image represented corresponds as well as possible to what the pilot may see from his cabin under good conditions of visibility.

The **position of the aircraft is with respect to the ground**. Today, that is called "altitude," but "altitude" is used in '972 to mean the elevation of a digital elevation point.

What does "attitude" mean? "Attitude" is always used in connection with "position" See above from Column 1, lines 35 – 41.

Column 1, lines 40 – 46:

> A processing circuit, connected to the memory storing the coordinates of the nodes of the network and receiving the data from the instruments measuring the position and attitude of the aircraft, then determines the image pixels to be illuminated and consequently controls a display device disposed in front of the pilot.

Column 4, lines 34 – 42:

> This synthetic image produced from information relating to ground 2 is stored in a memory, and information coming from instruments on board the aircraft concerning the position and attitude of the aircraft 8 with respect to ground 2, is presented to the observer in a known way, for example by means of a screen of the same size as the flat support 1 or of a different size, or else by means of a known device for superimposition of the real image.

There is no explanation of attitude. The common usage is that attitude is the orientation of the aircraft with respect to the ground. Mouchot's invention does not take into account the aircraft's orientation with respect to the ground. He does not even take into account the aircraft's heading.

This is what he actually does.

In Figure 1, the Point of Observation is Point P. It's on Airplane 8. The digital elevation database for the ground over which Aircraft 8 is flying is Ground 2. The color picture to be mapped onto Ground 2 is Map 5. The elevations in Ground 2 are interpolated [Column 6, lines 26 – 68] so there is an elevation for each pixel in Map 5. Each Map pixel is now associated with an interpolated elevation point and is called Point Q.

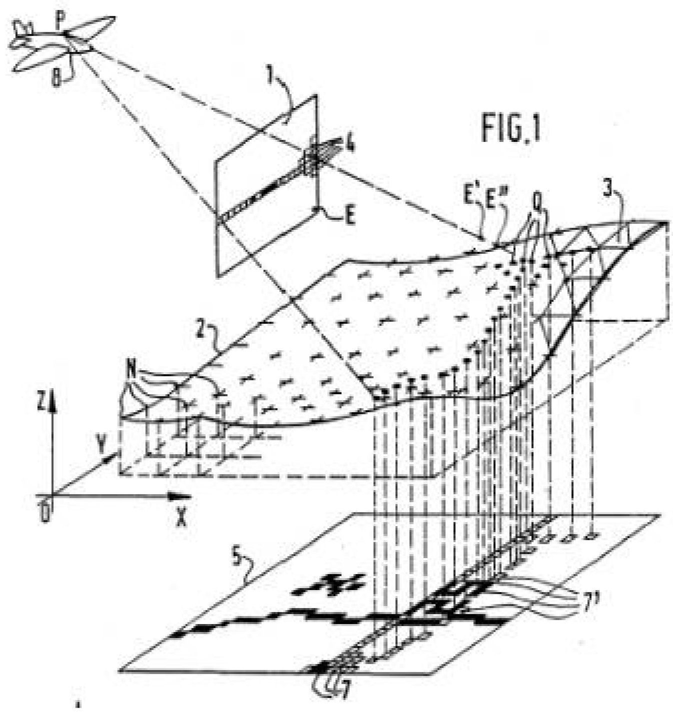
Then, in Column 5, lines 21 – 44:

> After defining the type of interpolation adopted, for each pixel 4 of the flat support 1 which belongs to the image of ground 2 the point Q of surface 3 which is associated with this pixel 4 and which is represented by

this pixel 4 may be determined, i.e. the first point of intersection Q of this surface 3 with the line which extends from point P and passes through pixel 4. The procedure for determining point Q will be described hereafter.

The planimetric coordinates X and Y of this point Q allow the pixel 7' of map 5 to be determined which is associated with this point Q of surface 3, i.e. in practice of ground 2.

As can be seen in FIG. 1, a horizontal line, for example, of image pixels 4 corresponds to a succession of points Q on surface 3 which draws a tortuous curve in space. This tortuous curve is obviously not projected on map 5 along a straight line, but along any curve. The result is that, by illuminating each image pixel 4 in the color of the map pixel 7' which is associated therewith, a deformed representation of map 5 is obtained, as if this map were drawn on the surface 3 itself instead of being drawn on a plane; the assembly is thus shown in perspective.



Mouchot interpolates elevation points from a digital elevation database, maps them onto a color picture, and displays the points in perspective. The big question is how he does the perspective.

The color map is arranged in rows and columns of color pixels. If he were to simply display the color map with the rows and columns of the map corresponding to rows and columns on the display the result would be simply a display of the color picture as shown in Figure 2.

A simple way to produce a perspective is to foreshorten the picture in the vertical direction.

The following is an example of a picture looking straight down.

In the following picture it has been foreshortened vertically to give it a perspective.

This is a linear compression method. The rows from bottom to top are all scaled by the same amount.

This is what Mouchot does, but he adds something special. That is where the digital elevation database comes in.

After mapping the color picture to an interpolated digital elevation database he now has an elevation associated with each color map pixel. He uses that information to do hidden point removal so that map pixels that are lower and farther away than nearer pixels are not displayed.

He starts with the corner of the color map that corresponds to the lower left corner of the display. He calls it Point E (Figure 1). As he scans up the column he performs a calculation to determine if the next pixel up is above or below a previously displayed pixel. If it is below a previously displayed pixel, he doesn't display it.

This process is shown in Figure 8 and involves:

Initializations (1061)
Calculations of the Progression Increments Along the Line (1062)
Incrementing the E' (New E) point (1063)
Testing the E'point to determine if it belongs on the display vector (1064)
Testing if the E' point is below ground (1067)
Dichotomy on the Coordinates E and E' Until Dist(E',E'< Threshold (1068)

What does he mean by *Dicotomy*?

Column 7, lines 20 – 39:

> For the lowest pixel of a column, point E is used, situated on the line which will leave from point P and passes through this pixel, and whose position is varied.
>
> Initially, this point E is on the flat support 1. Thus, it is certain that point E is above surface 3. After choosing a pitch D for progression along the line, the distance PE is increased step by step, observing each time the relative position of point E with respect to surface 3. As soon as point E is below surface 3, the point of intersection is sought by the known dichotomy method, i.e. the distance PE is reduced by D/2, then by D/4, and so on, i.e. by steps of a value each time equal to half that of the preceding step, until point E passes above surface 3. Then the distance PE is again increased in steps of a value each time equal to half that of the preceding step, i.e. by $D/2^{n+1}$, $D/2^{n+2}$, and so on, if the value $D/2^n$ was that which caused point E to pass above surface 3. This is continued, for example, as far as an increase in distance equal to $D/2^p$, which causes point E to pass below surface 3, and so on.

This *Dicotomy* is part of the interpolation process. Column 9, lines 44 – 55:

> Circuit 132 is adapted so as to work out the above described dichotomy and when the distance between two successive points is less than the above defined threshold $D/2^N$, it delivers a binary signal EG for controlling a gate circuit 134 which applies to the display device the signal PC' identical to signal PC representing the color of the map pixel 7' whose planimetric coordinates X and Y are defined by the signal SC, i.e. which are those of the point of intersection Q.
>
> Thus, we may say that the gate circuit 134 causes a map pixel 7' to be associated with each point of intersection Q.

The final result is that Mouchot teaches the use of a digital elevation database for hidden point removal in displaying a color picture that has been mapped onto the surface defined by the digital elevation database, using linear foreshortening to produce perspective, and displaying it in a system without a frame buffer.

What, no frame buffer?

Look at Figure 6. No frame buffer. This is being done during display-time.

Nowadays, frame buffers are ubiquitous. They are in every PC. But at the time the patent application that became '972 was filed, frame buffers were still expensive, typically several hundred dollars just for memory. PCs had frame buffers and PCs were expensive (typically $2,000) and they were too slow to do realtime graphics of the type Mouchot wanted to do. Atari owes its early success to its development of graphics hardware that did not use frame buffers. (This brilliant engineering was accompanied by equally brilliant game design.)

A frame buffer makes most of Mouchot's method unnecessary. Here's what you do.

1. Map the digital elevation database into the color picture by assigning an elevation to each pixel in the color picture. You can assign each block (defined by the intersection of the rows and columns) of the digital elevation database onto each block of the color picture or you can interpolate the elevations in the block.

2. The linear function used for projection is added to each pixel elevation. Thus, in order for a closer point to be higher than a farther point, its elevation must still be higher after the linear projection is taken into account.

3. Start by writing the row that is farthest away into the frame buffer. Then write the closer rows in sequence. Closer points that are in front of points that are farther away will overwrite them in the frame buffer, thus the points that are farther away will be “hidden.” It’s called *depth-sorting*.

Nowadays, the graphics cards in PCs use a *Depth-Buffer* (also called a *Z-Buffer*) that makes depth-sorting unnecessary.

Mouchot’s method does not account for the aircraft’s orientation in roll or pitch, does not account for the aircraft’s heading, and does not transform the terrain data to provide a three dimensional projected image.

It is not Synthetic Vision.
